WEST GATE BRIDGE – REFURBISHMENT OF DEMAG EXPANSION JOINT AND ROLLER BEARINGS

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ABSTRACT

Melbourne’s West Gate Bridge, first opened to traffic in 1978, is around 2.5km long and comprises an 848m long five-span steel box girder portion over the Yarra River and two continuous concrete box girder approach viaducts 871m and 670m long. The longitudinal expansion and contraction of the steel bridge and concrete viaducts is taken up at the two ends of the steel bridge, which are at Piers 10 and 15. At these piers, the ends of the steel bridge abut the end of the adjacent concrete approach viaduct.

This paper provides a description of the expansion joint and details of its performance and the major refurbishment works being undertaken on the joint. The joint is segmented and each stage of the refurbishment work must be completed within a 12-hour night shift and with limited lane closures to avoid unacceptable interference to the road traffic.

Furthermore, at both Piers 10 and 15, there are eight roller bearings under the steel bridge and the abutting concrete bridge. As well as describing the current remedial works, this paper presents a history of the problems encountered with the rollers, some of which relate to the original design and include broken gear teeth on the racks and pinions and bearing misalignment. The racks and pinions had originally been fitted to the rollers to maintain their alignment and this paper describes the programme of works currently underway to replace the racks and pinions on each of the rollers.

INTRODUCTION

The West Gate Bridge (WGB) spans the Yarra River just north of its mouth at Port Phillip Bay. It is a critical element in Melbourne’s road network and connects the Melbourne CBD with the western suburbs. The bridge was first opened to traffic in 1978.

The crossing is 2.5km long and comprises five steel box girder spans, with a total length of 848m, and eastern and western pre-stressed concrete box girder approach viaducts, 871m and 670m long respectively. Three out of the five steel box girder spans are supported through cable stays. Figure 1 below shows the general arrangement of the bridge.

The bridge was originally designed for 4 lanes of traffic with total daily traffic volumes of 40,000 vehicles per day. Currently, the bridge carries approximately 200,000 vehicles per day, nearly 15% of these being commercial vehicles, under a 5 lane per carriageway configuration. In recent years there have been substantial increases in both traffic volume and the size and mass of trucks using the bridge.

All longitudinal movements of both the steel and concrete superstructures are accommodated at the expansion joints and the roller bearings situated at Piers 10 and 15. The longitudinal movements that must be catered for include temperature changes, differential temperature effects, longitudinal wind, braking and acceleration, live load, and wind on live load.

Current ongoing maintenance works at the expansion joint involve the refurbishment and upgrade of the each component to ensure a functional system that provides for the movement of the bridge while maintaining a comfortable ride for the roadway users. At the same time, there is a program to refurbish the roller bearing components to ensure that the roller movement is perpendicular to its longitudinal axis with no bearing on the racks by the pinions.
For both the deck joints and the roller bearings, the refurbishment does not involve any significant design changes.

**Figure 1 - General view and locality plan of WGB**

**EXPANSION JOINT – DESCRIPTION OF THE JOINT**

A Demag roller shutter expansion joint was chosen by the original designers of the bridge. The joint is made up of many interconnected components and its concept is similar to that of a roller shutter door. As explained in more detail below, there is an articulated plate train (the equivalent of the shutter) attached to the end of the concrete bridge and a recess at the end of the steel bridge with a horizontal stool wearing plate which supports the plate train as it moves into and out of the recess. A tongue plate which covers the recess is attached to the steel bridge at one end and rests on the plate train at the other.

The original design provided for a total range of movement of 762mm, made up of 394mm for contraction and 368mm for bridge expansion. Subsequent reviews showed this range of movement to be some 38mm short of that required under the worst transient conditions. Hence, a system of buffers and chains was installed to maintain the joint’s serviceability. Both the buffer and chain systems were designed to prevent further closing or opening, respectively, of the expansion joint by transferring a force across the joint and flexing in the longitudinal direction of the two central piers to which the steel bridge is anchored.

There are two expansion joints, one above Pier 10 and the other above Pier 15. Each joint consists of 36 No. one metre wide trains of plates (72 No. in total), located transversely across the bridge deck. The plate trains comprise pendular, link and terminal plates and a tongue plate. See Figures 2 and 3 below for a labelled diagram of the components. Traffic loading applied to the expansion joint plates is transferred by the pendular plate to the concrete bridge pier diaphragm on one side, and a special curved support beam built into the end of the steel bridge on the other.
The movement is therefore accommodated by allowing the plate train assembly to pass along the stool wearing plate, supported on the curved beam, beneath a fixed tongue plate. At one end of the gap between steel and concrete superstructures the pendular plates are attached to the concrete viaduct by fixed blocks and holding down bolts. At the other end, the pendular plates are free to slide on the stool wearing plate. The pendular, link and terminal plates, which together make up a plate train, are attached to each other and to the concrete bridge with a system comprising wearing cams, bushes and pins and they slide over the curved stool wearing plates fixed to the steel bridge on the other side of the gap.

The tongue plate is attached to the steel superstructure at one end through a similar system of fixed blocks and holding down bolts to that of the pendular plate. It is tapered at the other end and rests on the plate train to produce a continuous smooth running surface.

For efficient operation of the joint, it is important that all joints are tight and in particular, that the sliding cams remain in contact with the wear plates at all times. If there are gaps, movement and impact occur when a vehicle passes over the joint and the resulting impact forces cause further deterioration in the tightness of the fit between the components.

This system of plate trains, comprising one meter wide single plates placed next to each other and sealed, renders the rolling connection almost water-tight. The tongue and pendular plates have a 5mm thick skid-free surfacing that increases driving safety and ride quality.

The overall condition of the joint on the West Gate is generally good despite having been in service for some 30 years. The refurbishment involves essentially maintaining the original design, replacing worn and corroded components, as detailed below, and making minor improvements to some of the detailing to make it more robust.
EXPANSION JOINT – REFURBISHMENT

General

The Demag joints are subject to detailed inspection once per year to check movement of the mechanism and confirm components are in good working order. Over the years these inspections have revealed the need for refurbishment works. The aim with the refurbishment work has been essentially to restore the expansion joint to its original state and to provide a smooth riding surface upon re-installation. Deterioration has been commonly apparent simply from the noise emitted by the joint as heavy trucks pass over it. The structure supporting the expansion joint has not required modification in any way although a number of welds are being visually inspected during the works.

Option Studies

Prior to the current round of plate refurbishment a study was undertaken of different refurbishment options for the WGB expansion joint. Previous papers (Sørensen et al, 2007) provide information on the major considerations. In addition to the refurbishment option currently being progressed the following options were also considered:

- Replacement of the joint with a new modular expansion joint; and
- Major maintenance overhaul of the existing roller shutter expansion joint.

At the time of the study it was recognised that although modular joints are being used in other longer bridges they still have their problems. The main reasons this option was not adopted were the higher installation costs, higher but difficult to quantify maintenance costs, more complex fixing and connection to the end of the concrete viaduct and, critically, the major disruption to traffic flows that would occur during the works.

The second option considered was a major maintenance overhaul which would not only reset the profile and levels on the stool plates but also remove the misalignment between plates and would employ self-lubricating sliding elements with an elastomeric spring at the support contact on the stool plates. This option did not progress due to higher costs, a major disruption to traffic flows and the fact that, this system is a proprietary technology that would require expertise not currently available in Australia for the maintenance work.

For both of these options, it would have been necessary to construct and maintain, for an extended period, a temporary elevated platform and temporary ramps to take the traffic over the joint and permit the work to progress under the elevated platform.

However, the outcome with the current works is less than ideal. It is therefore planned that the decision on these alternatives be reviewed in 5 to 10 years when the current refurbishment is complete and this review will include regard for the performance of the joints under the increasing traffic volumes on the bridge.

Refurbishment Works

Arising from the inspections and the refurbishment works the following have been identified.

- Stool plates worn to the point that original levels have been lost and pitting is visible on the stool wearing plate (Figure 4a);
- Cracking of stool wearing plate weld permitting rocking of plates as well allowing ingress of water under the stool plates which in turn has lead to pitting of the curved stool plate;
- Wearing cams welds failing due to incorrect detailing of the weld and insufficient penetration in the parent metal;
- Pins shearing due to shear loads being applied over the pin because of poor quality fit or wear in the bush and pin (Figure 4b);
• Pins coming loose due to poor quality of fit or wear in the bush and wearing cam;
• Springs within the holding down arrangements failing due to severe corrosion of the steel

![Figures 4a and 4b – Typical Deterioration of Expansion Joint Components. From left, (a) worn stool plate, failure of wearing cam to plate welds and (b) pins shearing off.](image)

The importance of the WGB in the Victorian road network and the current volume of traffic have restricted access for maintenance activities from the bridge deck. Accordingly, strict protocols have been established for the number and duration of lane closures permitted on the bridge. No lane closures are permitted during daylight hours on weekdays and at night some lanes must remain open at all times. The permitted lane closures are based on measured traffic on the WGB and ensure that the disruption to the traffic is kept to a minimum. The works require a minimum of three lanes to be closed for a period of 12 hours; hence scheduled refurbishment works can only take place Saturday night.

The current refurbishment process consists of the following:

• Removal of plate sets from the bridge using slings and a specially designed lifting beam, because of the awkward shape and location of the plate sets;
• Installation of new plate fixings that replace the old spring/collet arrangement with a bolted detail;
• Replacement of the stool wear plate to re-establish levels. The stool wearing plates are 255mm wide and are fixed to the curved beam by a fillet weld along each side. They are prefabricated, being cut and curved to the required profile using quenched and tempered steel. It is expected that the higher hardness of the material used will ensure that levels are maintained for a longer period of time which in turn will prevent the rocking motion of the plates trains;
• Re-installation of plate trains to the bridge, levelling the wearing cams, sliding blocks and the stool wearing plates so that the gap between sliding blocks on the one hand and the sliding block on the other and the stool plates is less than 0.05mm. This tolerance is very difficult to achieve at all times as the plate train moves relative to the stool plate with both seasonal and diurnal movement;
• Tensioning of the new holding down bolts once the plates are installed;
• Sealing of all longitudinal and transverse gaps between plates with an approved sealant. Sealing of gaps is necessary to prevent the ingress of water and grit to the working parts, hence prolonging the life of the joint; and,
• Off-site replacement of hinge pins, bushes and wearing cams as well as the installation of new wearing course and repainting. The manufacturing tolerances for wearing cam holes, bushes and pins have been refined to provide for the free rotation between plates while being tight enough to ensure pins do not rattle and work loose. Trials have also been undertaken to confirm that the redesigned welds between wearing cams and plates do not fail due to fatigue.
It is expected that the service life for a plate set refurbished in this manner will be around 8 to 10 years, with the current refurbishment programme having already commenced in 2010.

**Lessons Learnt and On-Going Work**

Although the current maintenance regime is providing a joint that is operational, the constraints under which the refurbishment work is being performed are less than ideal for an optimum outcome. Despite great care with the fitting of components, some rocking of bearing surfaces still tends to occur post-refurbishment and this rocking leads to wear and other deterioration. If there are imperfections in the accuracy of fit of the two wearing cams, then only one of the two wearing cams will contact the stool wearing cam during the load cycle. As a result even though the joint will operate, it will do so with noise and wear due to a hammering effect.

A shortcoming of the concept is that the support is redundant in that each load carrying plate is supported at four points, which makes elimination of gaps difficult. Although extreme care is taken during assembly to ensure a close tolerance fit at all bearing surfaces, once the plates commence rocking under traffic loads, rapid deterioration of the joint inevitably occurs. The initiation of such a rocking motion is likely to be due to relative movements of the concrete and steel bridge transverse profiles under the action of differential temperature.

In the light of experience from overseas and our own experience on WGB, it is clear that the components likely to require remedial work in the future will be those associated with the sliding mechanism.

Furthermore, at the WGB there are several types of plate misalignment. One is transverse between adjacent joints which, despite considerable efforts to correct this problem, causes the tongue plates to straddle and be supported by two adjacent plate trains. Consequently the end result with the uniformity of support of the tongue plate is less than ideal. A second misalignment relates to the level differences between adjacent plates. Ideally, minor adjustments should be made to the position of all plates to correct such misalignment; however, due to time constraints these adjustments cannot be achieved as part of the current refurbishment works.

Finally, the key point is that there is no change to the principles behind this expansion joint system and as such there will still be continuing metal-to-metal impact and abrasive contact which will continue to result in on-going wear and deterioration.

**ROLLER BEARING – DESCRIPTION**

At the top of each of Piers 10 and 15, two roller bearings support the end of each of the concrete viaduct and the steel bridge, a total of eight (8) No. roller bearings.

The roller bearings accommodate expansion and contraction of the bridge superstructure due to temperature effects, the currently anticipated range of movement being 480mm for the steel bridge and 330mm for the concrete viaducts. In addition, the roller bearings experience smaller short-term movements, on a regular basis, resulting from transient load effects such as bridge traffic and wind. The original design also included allowance for the effects of creep and shrinkage of the concrete viaducts, although most of these movements are now complete.

The roller bearings transmit all vertical loads from the bridge superstructure to the bearing blocks positioned atop Piers 10 and 15. The design load for the bearings is 900 ton for the concrete bridge and 600 ton for the steel bridge. Flanges at each end of the roller shaft prevent the rollers from moving transversely and sliding out from between the bearing plates. In addition, they provide a measure of lateral restraint against transverse bridge movement. However, because of the sheer size and stiffness of the bridge, the resistance that these flanges provide against lateral movement of the bridge is minimal.

The roller bearings supporting the steel and concrete superstructures are similar in arrangement, primarily differing only in shaft length, 1.5m for the steel bridge and 0.8m for the concrete bridge. All rollers are hard-chrome plated for corrosion protection.
An arrangement of racks, pinions, wear plates and packing plates is provided at each end of the roller. The racks and pinions are included to maintain the alignment of the roller shaft, while the packing plates correct for minor misalignments between the top and bottom bearing plates. A high pressure lubricant is applied to all contact surfaces of the roller bearing and the entire arrangement is enclosed within a protective shroud. Figure 5 shows a typical roller bearing with the shroud removed.

**Figure 5 – Typical West Gate Bridge Roller Bearing (with shroud removed)**

## ROLLER BEARING – MAINTENANCE

### Maintenance History

The roller bearings have been subject to various maintenance works and adjustment since they were originally installed on the West Gate Bridge in the early 1970s. Initially, only the roller bearings supporting the concrete viaducts were fitted with flanges on the end of the roller shaft. This inclusion was based on an expectation of lateral movements resulting from the straightening of the horizontally curved concrete viaducts due to creep and shrinkage, effects which were not expected to arise with the straight steel bridge and its bearings.

In 1977, prior to the bridge opening to traffic, several concrete bridge roller flanges had already cracked or fractured. In response, a restraining tie was installed to reduce the outward movement that had occurred with the concrete spans at Piers 10 and 15. The restraining devices were arranged diagonally to pull from the top of the pier to the opposite side of the concrete viaduct (refer Figure 6). At one stage, this restraining device over-corrected the problem, causing the viaducts to move inwards and break the flanges on the other end of the rollers as well as causing damage to some of the rack and pinion components. However, the exercise was eventually successful, the restraints were removed in 1985 and there has been no recurrence of this particular problem since.

**Figure 6 – Arrangement of restraining device employed to correct concrete viaduct lateral movement**
In response to the damage that had occurred and given that the lateral restraining exercise had been successful, works were carried out to replace the bearings in 1991. At the same time, misalignments between the top and bottom bearing plates on the steel bearings were giving rise to similar issues (Figure 7). Dealing with the misalignment required that the rollers be made longer so they were also replaced as part of the 1991 works.

![Figure 7 – Flangeless roller shaft for steel bridge and misalignments between bearing plates (1989)](image)

This programme of works provided new rollers at all bearings, which included lateral restraint flanges for both the steel and concrete rollers (Figure 8). Jacking of the bridge enabled removal and reinstatement of the rollers, and subsequently new rack, pinion and alignment-correcting packing plate elements were installed.

![Figure 8 – Typical cross-section of steel bridge roller bearing following 1991 replacement](image)

**Key Maintenance Issues**

Although the rollers have generally performed satisfactorily since they were replaced in 1991, there has been a need for ongoing, albeit minor maintenance works. The defects that have given rise to these works include:

- Poor fit between the racks and pinions
- Worn and broken gear teeth on both the racks and pinions
- Sheared and bent fixing bolts on the racks
- Lateral movement of the roller along its axis.
These developments have in turn given rise to further damage, including:

- Tilted and dislodged racks
- Interference between the roller flanges and the adjacent racks
- Excessive wear and indentation of the wear plates by the roller flange
- Misalignment of one of the rollers

Consequently, a package of refurbishment works was assembled in 2013 to remedy the defects and limit further deterioration.

![Figure 9 – Typical rack and pinion damage, from left, cracked and worn gear teeth, dislodged racks and sheared fixing bolts](image)

**Roller Alignment**

An essential requirement of the roller bearing system is that the movement of the roller is perpendicular to its longitudinal axis. Were this not the case it would involve a component of roller movement which is not perpendicular to its axis, and by inference, the presence of skidding or sliding of the roller shaft across the bearing plate giving rise to increased wear of the roller contact surfaces or unbalanced and erratic movements and damage to racks, pinions or roller flanges.

During initial visual inspections and investigations for the current package of refurbishment works, it was found that at least one roller bearing, Roller Bearing 10A, was misaligned by approximately 14mm over its 1.5m length. It was therefore determined that the alignment of all rollers should be checked.

The initial approach for measuring the roller alignment involved directly measuring fixed points upon the roller shaft utilising traditional survey equipment mounted on the bridge pier. Measurements were taken over several days and across the roller’s typical range of movement. However, due to the combination of survey instrument tolerances and the limited movement, this method did not provide a measure of the roller alignment to the required level of accuracy.

The final solution involved a set of electronic movement transducers set up against a known reference datum. Separate transducers were employed to provide direct simultaneous monitoring of the roller bearing on two perpendicular reference axes. To ensure accurate axial measurement, precisely mounted stainless steel plates were fixed to the ends of the rollers. These plate surfaces were machined smooth prior to installation and subsequently coated with a lubricating film to provide a suitable surface for the transducer probes.

The transducers provided measurement accuracy to within 0.2mm, which was considered acceptable given the magnitude of the measurements being observed.
Key Considerations for Satisfactory Performance

The satisfactory performance of the roller bearing arrangement is largely reliant on satisfaction of several key requirements (refer Oladimeji Fasheyi, 2012 for further detail).

**Pinion pitch circle diameter**

It is important that the pitch circle diameter (PCD) of the pinion precisely matches the effective rolling diameter of the roller to which it is affixed. This effective diameter must account for the deflected shape of the roller under operating load.

Investigation of the existing rack and pinion details as originally designed in the 1960s, has shown that, in some cases, the pitch circle diameter of the pinion is marginally greater than the effective diameter of the roller to which it is fixed. This mismatch gives rise to increased load on the gear teeth of the rack and pinion and the need for some skidding of the roller relative to the bearing plate it is contacting rather than simply a rolling motion, thereby contributing to the deterioration of the gear teeth.

**Relative location of rack and pinion pitch lines**

The roller bearing racks and pinions are not intended to provide a load path for the support of the bridge superstructure, rather all dead and live load from the superstructure must be taken by the roller shaft. The racks and pinions are simply included to maintain the alignment of the roller shaft.

To prevent jamming of the gear teeth, the spacing of the racks is set such the dedendum line of the rack is not precisely tangential to the addendum circle of the pinion. The rack pitch lines are set a short vertical distance from the pitch circle of the corresponding pinions, with the upper rack pitch line 0.5mm above the pinion pitch circle and the lower rack line 3mm below the pinion pitch circle.

**Standard for machining**

A high level of dimensional accuracy is needed to ensure optimum operation and compatibility of the roller bearing components in service.

Given the intentional working clearances and slow movement cycle of the gears an AGMA Class 5 gear cut was adopted to provide an appropriately precise, yet not precision grade, gear cut that was reasonably attainable.

**Current Maintenance Works**

**Lateral repositioning of roller bearing 15D**

In 2013, preparatory works were performed on Roller Bearing 15D to adjust the transverse position of the roller shaft which had caused its flange to bear against and damage the existing lower wear plate. The purpose of the repositioning was to permit removal and replacement of the wear plates.

This axial movement was achieved through the use of a shim with a 1/200 taper inserted between the roller flange and the upper bearing plate. As the roller moved through its normal range of motion due to thermal effects, the tapered section caused the roller to gradually translate along its axis and disengage from the lower wear plate.

The targeted 2mm of axial roller movement was achieved over a 10 week period, with daily resetting of the shim to ensure continued effective engagement. Lubrication between the tapered shim and roller flange was also provided to ensure that snagging of the roller on the shim did not occur.
Refurbishment of racks, pinions and plates

Due to the condition of the existing components, all existing roller bearing racks, pinions and wear plates are proposed to be replaced with newly manufactured and suitably dimensioned components.

The refurbishment will provide for new pinions with a PCD that precisely matches the effective diameter of the corresponding roller. Additionally, adjustment to the packer thicknesses at each bearing will ensure that fouling of the racks and subsequent fracturing of bolts does not occur.

In 2013, a trial refurbishment of Roller Bearing 15D was completed to assist with planning for refurbishment of the remainder of the bearings. Significant effort was directed towards development of a replacement methodology that ensured the required level of accuracy was achieved and that the length of time for which the roller was left unrestrained by the racks and pinions was kept to a minimum.

Particular challenges were presented when taking in-situ measurements due to the continual movement of the roller caused by fluctuations in the live load on the bridge. Considerable attention was also required for the final fitting together of components, especially to ensure bolt holes in the new components matched precisely the existing bolt holes in the bearing plates. Due to the level of precision required to achieve accurate pitch line positioning, all bolt holes were drilled offsite in the workshop.

Key factors in the achievement of a satisfactory outcome were the cross-checking of measurements, and the use of an accurate CAD model for each bearing.

Re-alignment of Roller Bearing 10A

In the case of Bearing 10A, there was a need to realign the roller. This realignment has yet to occur but will be achieved by taking the bridge load off the roller using jacks set up on the top of the pier. Investigation of bridge jacking as a means to achieve this outcome was underway at the time of writing this paper. It is expected that detailed investigation of both local and global effects due to the jacking load will be required to determine suitable jacking points. The refurbishment of racks and pinions at this roller bearing will proceed once the roller realignment is completed.

Skirt design

Protective shrouds (or skirts) are currently installed on all roller bearings to protect the roller bearings from damage due to debris, foreign objects and dust. The skirts also provide a sealed environment against the effects of weather to maximise the useful life of the protective, lubricating grease on the bearings.

![Figure 10 - Typical view of replacement skirt for steel bridge bearings](image)

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The redesigned skirt (refer Figure 10) accommodates total bridge movements of up to 480mm due to bridge thermal effects and is designed to be easily removed and re-instated. The skirt incorporates a rubber membrane that can accommodate these large movements and still provide the required seal around the bearings.

The skirts will be fitted with a hinged viewing window at each end of the roller to permit inspection of the racks and pinions without removal of the skirt. It is expected that the replacement skirts will provide increased protection to the roller bearings as well as significantly improved access for routine maintenance tasks such as inspections and re-greasing.

**CONCLUSION**

Substantial refurbishment works are being progressed with the Demag expansion joints on West Gate Bridge. Whilst the joint has performed well for the life of the bridge to date, the refurbishment will result in substantial improvement to the fit of the components and the ongoing serviceability of the bridge. Given the constraints arising from the need to limit interruption to traffic, the outcome is however less than ideal.

Over the life of the bridge it has been found necessary, from time to time, to undertake maintenance work on the roller bearing supporting the bridge, including replacement of the rollers in the early 1990s. The current works involve replacement of the racks and pinions at the ends of all rollers. A critical success factor with these works is the accuracy with which the gears are fitted to achieve good meshing of the gear teeth. Good meshing reduces the load on the gear teeth thereby limiting deterioration.

**REFERENCES**


**AUTHOR BIOGRAPHIES**

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